D5-13268-1

VOLUME I

SUMMARY TECHNICAL REPORT

PASSIVE INSTRUMENTATION AND STIMULI GENERATION FOR SATURN 1B EQUIPMENT CHECKOUT

THE BOEING COMPANY • SPACE DIVISION

Passive Instrumentation and Stimuli Generation For Saturn IB Equipment Checkout

Period of Performance: 26 June 1965-31 May 1966

Henry N. Kaushagen
Program Manager

Kenneth L. Skinner
Technical Supervisor

Study Team

S. R. Nelson
R. H. Alexander
R. J. Fortier
W. L. Heintschel
M. J. Judge
C. C. King
D. Q. Krebs
R. S. Trumbull

ABSTRACT

This document is Volume I, Summary Technical Report, of the Final Technical Report of the Passive Instrumentation and Stimuli Generation for Saturn IB Equipment Checkout study for the George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Alabama, under Contract NAS8-20090.

The final technical report consists of four volumes:

D5-13268-1	Summary Technical Report
D5-13268-2	Detailed Technical Report
D5-13268-3	Appendix A, Laboratory Report
D5-13268-4	Appendix B, Instrument Unit Data Sheets

SELECTED KEY WORDS

Passive Instrumentation
Passive Sensing
Noncontacting Instrumentation
Noncontacting Sensing
Secondary Effect Instrumentation
Secondary Effect Sensing
Sensing Techniques
Stimulus Techniques
Test Coupling
Stimulus Coupling
Response Coupling
Instrumentation Coupling
Test Technology
Space Vehicle Instrumentation
Infrared Testing
Thermal Testing
Magnetic Testing
Electrical Testing
Chemical Testing
Nuclear Testing
Mechanical Testing
Acoustic Testing
Ultrasonic Testing
Missile Testing
Space Vehicle Testing

CONTENTS

LIST OF FIGURES

LIST OF TABLES

FOREWORD

This document is a technical report for a study of Passive Instrumentation and Stimuli Generation Techniques Saturn Equipment Checkout conducted by The Boeing Company, from June 26, 1965 to May 31, 1966, for the Quality and Reliability Assurance Laboratory, NASA, George C. Marshall Space Flight Center. The purpose of the study was to perform an extensive investigation of passive techniques and methods of application to the Saturn Instrument Unit, define appropriate passive techniques, define the types of components that the techniques should be adapted to, determine methods of coupling into and out of a component or a system, and define the stimuli generation and response evaluation equipment. The systems of the Saturn Instrument Unit were used for detailed investigation as being representative of the types of space vehicle systems to which passive techniques should be applied.

Passive instrumentation and stimulus generation techniques are defined for the purposes of the study as, "those techniques for passively introducing stimuli and extracting responses from vehicle systems without impairing, altering, or affecting the system operation."

Limited experimental work was performed in the laboratory during the course of the study to verify several of the more promising techniques.

Included in the study report are conclusions and recommendations for further activity. Although the study was conducted for the Saturn-IB Instrument Unit, the techniques apply equally as well to the Saturn V Instrument Unit.

1.0 INTRODUCTION

The purpose of the study was to investigate techniques for passively injecting stimulus into and extracting information from space vehicle systems typified by the Saturn vehicle Instrument Unit systems.

For clarification, the term passive, as applied to instrumentation and stimulus generation techniques in this report, is defined as "those techniques which make it possible to introduce stimuli into and extract responses from vehicle systems without impairing, altering, or affecting functional system operation." While the majority of the passive techniques discussed in this report are also noncontacting, any technique which falls within the above definition can be considered passive.

Noncontacting passive techniques include such familiar activities as the sensing of infrared radiation from components, sensing magnetic fields resulting from current flow, sensing electromagnetic radiation from faulty components and circuits, and sensing acoustic noise from failing bearings or leaks. Techniques for coupling stimuli into systems in a noncontacting manner include magnetic field coupling and light-coupled excitation of a photosensitive device. These techniques, and others as they were identified, were analyzed and the appropriateness of their application to the Saturn Instrument Unit determined.

Initial activity during the study period was devoted to a literature search to ascertain the work that had already been accomplished in the field of passive instrumentation. From the literature search, and from consideration of secondary effects known or expected to exist in the Saturn Instrument Unit, a preliminary listing of passive techniques was compiled. It became apparent early in the study that identified techniques could most logically be grouped into phenomenological categories. By so doing, additional techniques were identified, and a more logical study approach was possible.

During the study, it was deemed beneficial to verify certain techniques experimentally in the laboratory. To support this verification, flight hardware was provided on loan from the Quality and Reliability Assurance Laboratory. Verification of passive sensing and stimulus coupling were demonstrated using this hardware.

Passive instrumentation is a natural outgrowth of the nondestructive testing prevalent in the mechanical field. Developments in nondestructive test techniques led to speculation on the possibilities of nondegrading or nondestructive testing in other fields, particularly electronics.

Since 1962, work has been contracted by Aero-Propulsion Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, relative to passive testing techniques. Technical Documentary Report APC-TDR-64-4, was entitled, "Investigation of Secondary Phenomena for Use in Checkout." This document describes work done at Systems Research Laboratories, Inc., Dayton, Ohio, and discusses X-ray, infrared, contract thermography, RF fault detection, magnetic field, and other techniques potentially applicable to test and checkout operations. Illinois

1.0 (Continued)

Institute of Technology also has done work for the same laboratory on secondary effects, largely related to chemical and magnetic techniques. The final engineering report on this study was published recently.

In customary approaches to testing, the coupling between the item under test and the test system is direct. Voltage is sampled directly by solid-state or relay switching, current by sensing voltage drop across a resistance inserted into the line, and pressure is sensed by a bellows-operated (or otherwise direct coupled) potentiometer, etc. With these direct coupling techniques, certain drawbacks become obvious. Relays fail in many ways, frozen contacts can indicate an erroneous condition, and solid state switches can fail and couple-in undesired signals.

Desiring to overcome these known deficiencies, and considering the appreciable work that had been accomplished in non-contacting instrumentation, this study contract was begun to determine further work to be done, collect the data, analyze the data, define its applicability to the Saturn Instrument Unit, and recommend areas for further research.

2.0 SELECTION OF APPROPRIATE PASSIVE TECHNIQUES

The contract statement of work called for a one month literature search to ascertain the work which had already been performed in the general field of passive instrumentation. This literature search resulted in examination of approximately 2,000 titles and abstracts and the accumulation of some 360 documents considered appropriate to the conduct of the study. The results of the literature search were utilized as a basis and point of departure for performing the analysis of passive instrumentation and response measuring techniques for the remainder of the study.

The remainder of the study was devoted to the detailed analysis of the more promising techniques identified during the literature search. It was deemed beneficial during the study, to verify certain techniques experimentally in the laboratory. To suppor this verification, flight hardware was provided on loan from the Quality and reliability assurance laboratory. Verification of certain passive sensing and stimulus coupling techniques was demonstrated using this hardware.

As there are approximately 400 physical laws and effects which may be applicable to passive instrumentation, it was necessary to establish criteria for the selection of those techniques which should be treated in detail. The criteria chosen for identifying passive techniques for consideration during the conduct of this study were:

a. The parameter to be sensed or stimulated shall be one that is found in the Saturn vehicle Instrument Unit;

b. The sensing or stimulation should be capable of accomplishment on-board the vehicle;

c. Implementation of the techniques shall be practical in the near future.

d. The effect must be recognizable and easily interpreted;

e. The effect shall be constant and predictable; and

f. The technique shall be relatively unaffected by the environment.

The approach to the analysis portion of this study required the categorization of techniques to permit a logical development of their applicability. Each of the techniques analyzed was found to logically fit within one of five phenomenological areas:

a. Magnetic and electric field phenomena,
b. Infrared and heat phenomena,
c. Optical and luminescent phenomena,
d. Nuclear, X-ray, and chemical phenomena, and finally
e. Mechanical and acoustic phenomena.

Approximately 35 individual techniques or methods were investigated in detail during the course of the study. Each of these techniques is treated in detail in Volume II,

[redacted]

2.0 (Continued)

Detailed Technical Report. From the analysis and the laboratory experiments conducted during the study, certain techniques were selected as being appropriate for passive instrumentation of the Saturn vehicle Instrument Unit within the context of the study and with regard to the selection criteria described earlier.

The selected techniques are:

a. Hall effect device;
b. Magnetoresistor;
c. RF Monitoring;
d. Metal oxide semiconductor - field effect transistor (MOS/FET) electrometer;
e. Photon and thermal sensors;
f. Transistor thermometer;
g. Semiconductors emitters and sensors;
h. Incandescent emitters; and
i. Ultrasonic-flow measurement.

A brief description of these techniques is contained in Section 3.0 of this document.

Other passive techniques that were studied, but were not considered as fulfilling the criteria established are shown below:

a. Fluorescent thermography;
b. Cholosteric liquid crystals;
c. Chemical coatings;
d. Chemical seedings;
e. Nuclear-magnetic resonance;
f. Radiation measurement;
g. Mössbauer effect;
h. Mass spectrometer;
i. Radiography;
j. Resonant-beam flowmeter;
k. Electromagnetic flowmeter; and
l. Acoustic noise.

These techniques did not comply because of bulky equipment required, non-reversable operation, visual interpretation required, undesirable radiation levels, and atmosphere required for operation.

For the selected passive techniques, a large number of parameters were identified for which the techniques were applicable. Using the selected techniques, methods were developed to passively instrument the following parameters:

2.0 (Continued)

a. Voltage;
b. Current;
c. Power;
d. RF noise;
e. Displacement - linear, angular, and rate;
f. Termperature;
g. Flow rate; and
h. Contracts - electrical and thermal quality

Other stage parameters of interest such as vibration acceleration and structural integrity are presently passively instrumented. Suitable passive techniques were not uncovered for fluid level, pressure, or leakage.

3.0 DESCRIPTION OF SELECTED TECHNIQUES

3.1 INTRODUCTION

The purpose of this section is to provide a brief description of each of the selected passive techniques.

3.2 MAGNETIC AND ELECTRIC FIELD TECHNIQUES

In the magnetic and electric field technique group, the Hall effect device, the magnetoresistor, the RF monitoring techniques and the metal-oxide semiconductor field-effect transistor (MOS/FET) electrometer offer great promise.

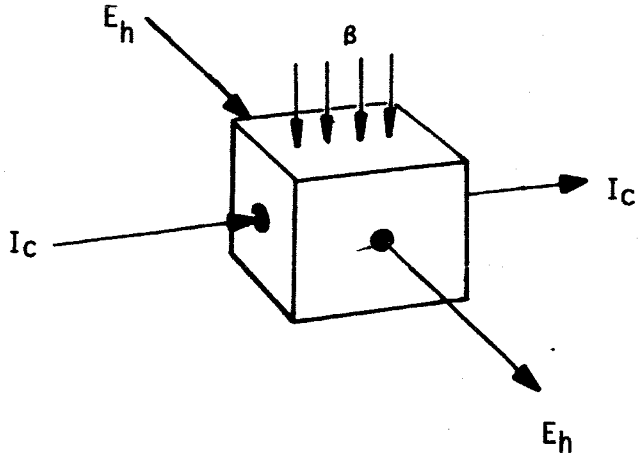
The Hall effect device, Figure 3-1, represents a most attractive means for measuring a magnetic field, and appears to have a rather wide application on the Saturn Instrument Unit. The device is a semiconductor which exhibits a linear output (E_h) as a function of the mutually perpendicular flux (β) and control current (I_c). These devices have a sensitivity appropriate for the electromechanical devices found in the vehicle, a good frequency response, and small physical characteristics. One disadvantage of the Hall effect device is the control current requirement shown in the figure. However, the forward voltage drop through the device is small, permitting connection of many devices in series for operation from a standard power source.

Another most promising device for application in the magnetic and electric field area is the magnetoresistor, Figure 3-2. The magnetoresistor exhibits a variation in resistance as a function of flux. As shown in the figure, this variation is sufficiently large to provide good resolution in measuring the magnetic field.

During the experimental activities conducted during the study, several relays, solenoid actuators and solenoid valves were instrumented with Hall effect devices and magnetoresistors. Very good results were obtained for determining application of power to the coils, time of operation for the armature, indication of sticky contacts both open and closed, and the degree of armature travel. In addition, non-magnetic devices, such as motor shafts were seeded with magnets, and longitudinal and angular position as well as angular rate was determined.

Experimental data was also obtained for modulators utilizing Hall effect and magnetoresistor elements. Carrier suppression and linearity achieved were excellent, and the government-furnished flight control computer was successfully tested by stimulating the amplifiers with these modulators.

Incipient failures in electronic components are detectable by an increase in RF noise from the failing part. This noise is broadband, and is exhibited by resistors, semiconductors and electrical joints/contacts. The radiation is apparently caused by an arcing mechanism in the component.



β	.1 - 30k GAUSS
I_c	50 - 150 mA (@ APPROX. 200 mV)
E_h	10 μV - 100 mV
BAND WIDTH	DC - 1 mHz
PHYSICAL	.5 x .25 x .03 inches
	.05 x .05 x .01 inches

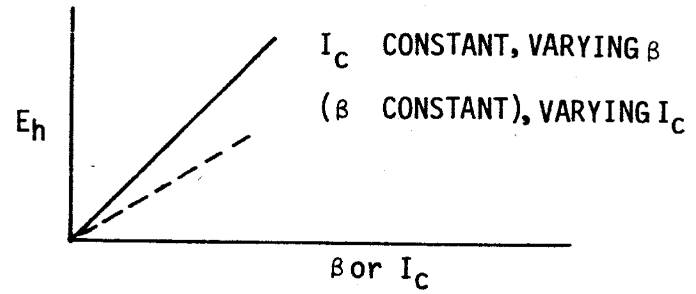
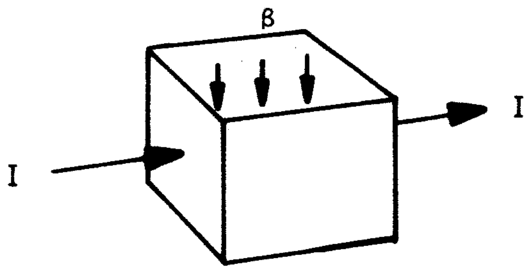
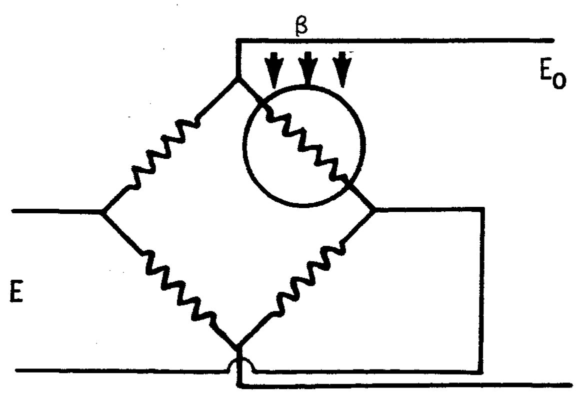


Figure 3-1: HALL EFFECT DEVICES



β	.1 - 30k GAUSS
BAND WIDTH	DC - 1 mHz
$\frac{\Delta R}{R_o}$ (I CONNECTIONS)	4%/KILOGAUSS

(INITIAL R_o 100 - 10,000 Ω)
PHYSICAL - SAME AS HALL-EFFECT DEVICE



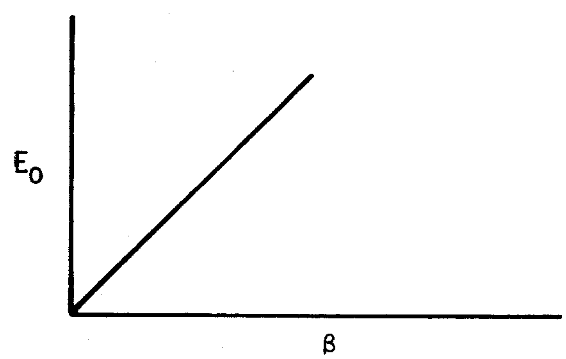


Figure 3-2: MAGNETORESISTOR

3.2 (Continued)

Hand-held probes, shown schematically in Figure 3-3, are commercially available and exhibit a sensitivity on the order of 5 to 40 db above ambient noise, permitting their use in isolation to a circuit board or to a component on the board. They are tuned to approximately 27 mHz to take advantage of low ambient noise.

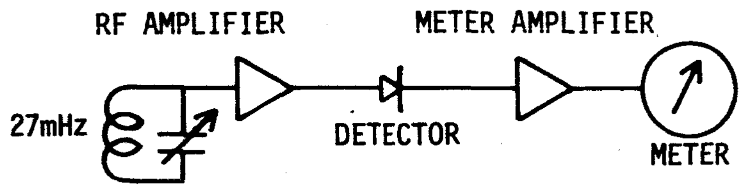


Figure 3-3: RF MONITORING

The metal-oxide semiconductor-field-effect transistor (MOS/FET) electrometer is a valuable device for measuring low voltages. Although the device required hardwire connection to the test point, it is passive in that it can be used without impairing, altering, or affecting the functional system operation. This is possible since the device makes use of the high gate/source resistance of the FET, thereby providing isolation in the order of 10^{12} ohms. The MOS/FET electrometer is shown in Figure 3-4.

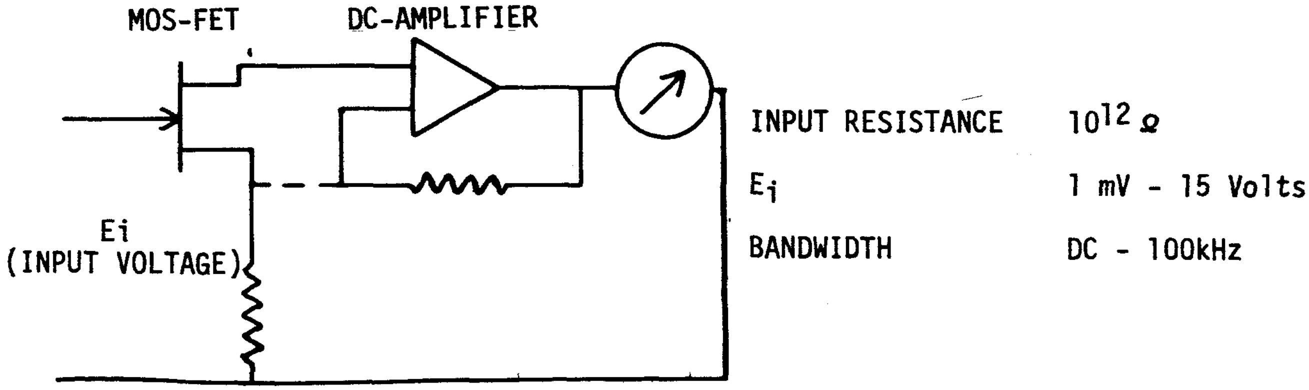


Figure 3-4: MOS/FET ELECTROMETER

Commercially available devices of this nature are currently appearing.

3.3 INFRARED AND HEATING TECHNIQUES

The use of infrared and heat techniques is, of course, directly applicable to measuring termperature. Heat, however, is a by-product or secondary effect of other vehicle parameters such as power dissipation, electrical and thermal quality of contacts, operating profile of modules, friction and flow rate. Photon and thermal sensors were determined to be most applicable in this area.

3.3 (Continued)

Photon sensors are available operating to 14 microns and, with associated optical components, are compatible with fault isolation down to component parts on an etched circuit board. Figure 3-5 shows some typical responses for different detectors at various temperatures.

Thermal sensors of compact size are available as both semiconductors and bolometers. These sensors are useful over a much wider temperature range than photon sensors. Their primary usefulness is in the measurement of static or quiescent power levels, since their frequency response is limited by the physical heat sink characteristics of the sensor. They are normally used in direct contact with the source being measured. Figure 3-6 shows their characteristics.

The semiconductor sensor shown in Figure 3-6 is a transistor thermometer.

3.4 OPTICAL AND LUMINESCENT TECHNIQUES

Application of optical and luminescent techniques to passive instrumentation is primarily one of decoupling, since none of the vehicle parameters can be directly measure using these techniques.

By using semiconductor emitters and sensors, incandescent emitters, and enhancement techniques such as fiber optics, optical lens, reflective coatings and gratings, the optical and luminescent area can be made to yield meaningful data for voltage, current, vibration, position, rate and temperature.

Shown schematically in Figure 3-7a and b are two applications of optoelectronics. In Figure 3-7a a photo diode has been installed as an additional component in a functional system. It serves as a light emitter, and a photo diode sensor is used in the monitoring circuit. Figure 3-7b shows application of light-sensitive field-effect transistors (FotoFet) for switching the input to a subsystem or system and as a gain-changing switch for an operational amplifier. These applications were substantiated in the laboratory during the course of the study.

3.5 MECHANICAL AND ACOUSTIC TECHNIQUES

The most promising technique uncovered in the mechanical and acoustic technique area is the ultrasonic flow meter. Ultrasonic techniques have been used to measure flow with the transducers coupled directly to the fluid. They have also been used to measure flow passively, with the transducers clamped to the outside of plastic tubing. Laboratory investigation during the study revealed that sufficient energy could be coupled through metal pipes to perform meaningful measurements of flow rate. The technique takes advantage of the differing propogation velocities in the pipe and the fluid. An ultra-sonic discontinuity in the pipe, normally provided by joints, elbows, valves, tees, etc., is required. Figure 3-8 shows the characteristics of this technique.

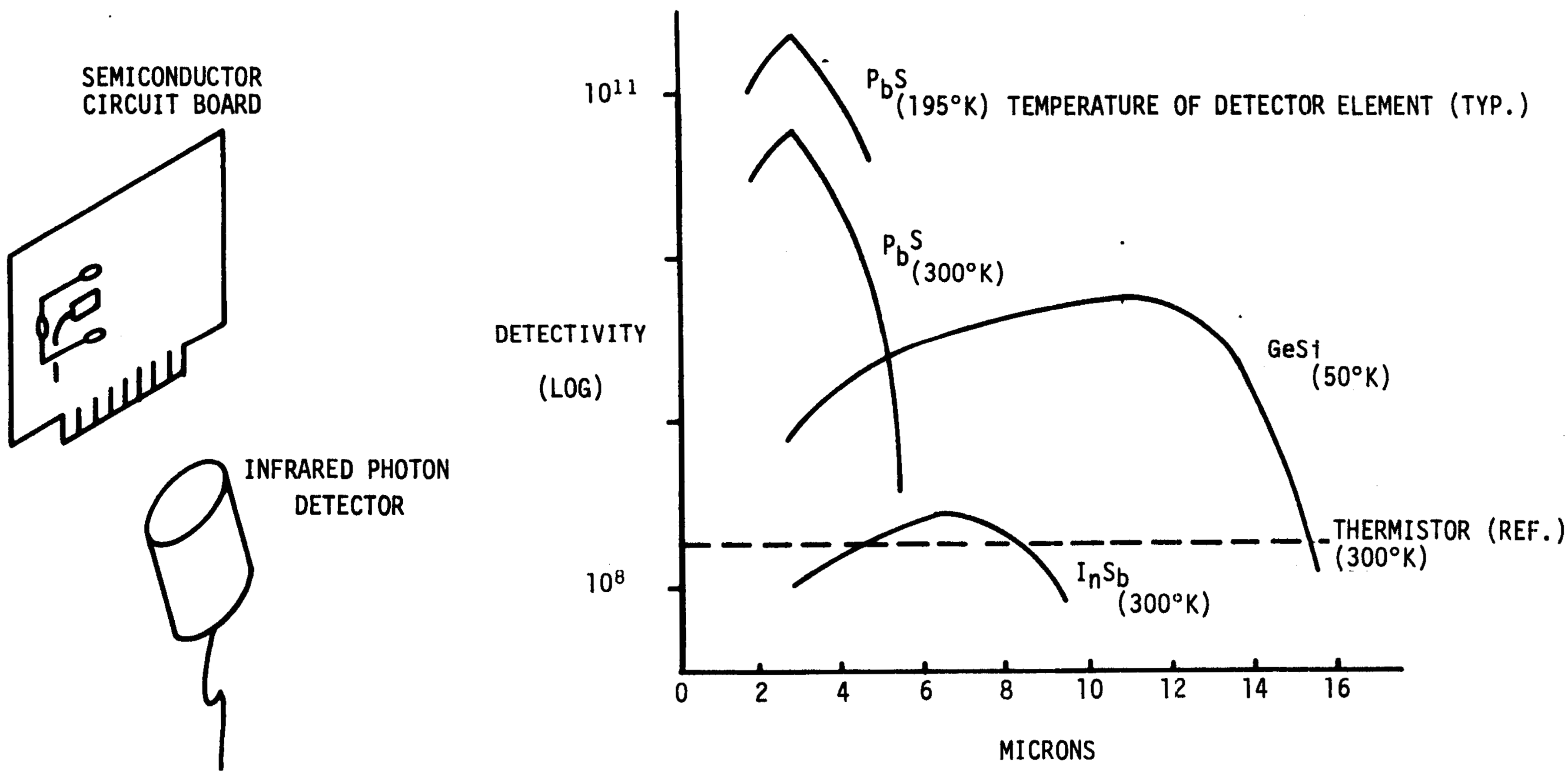


Figure 3-5: PHOTON SENSORS

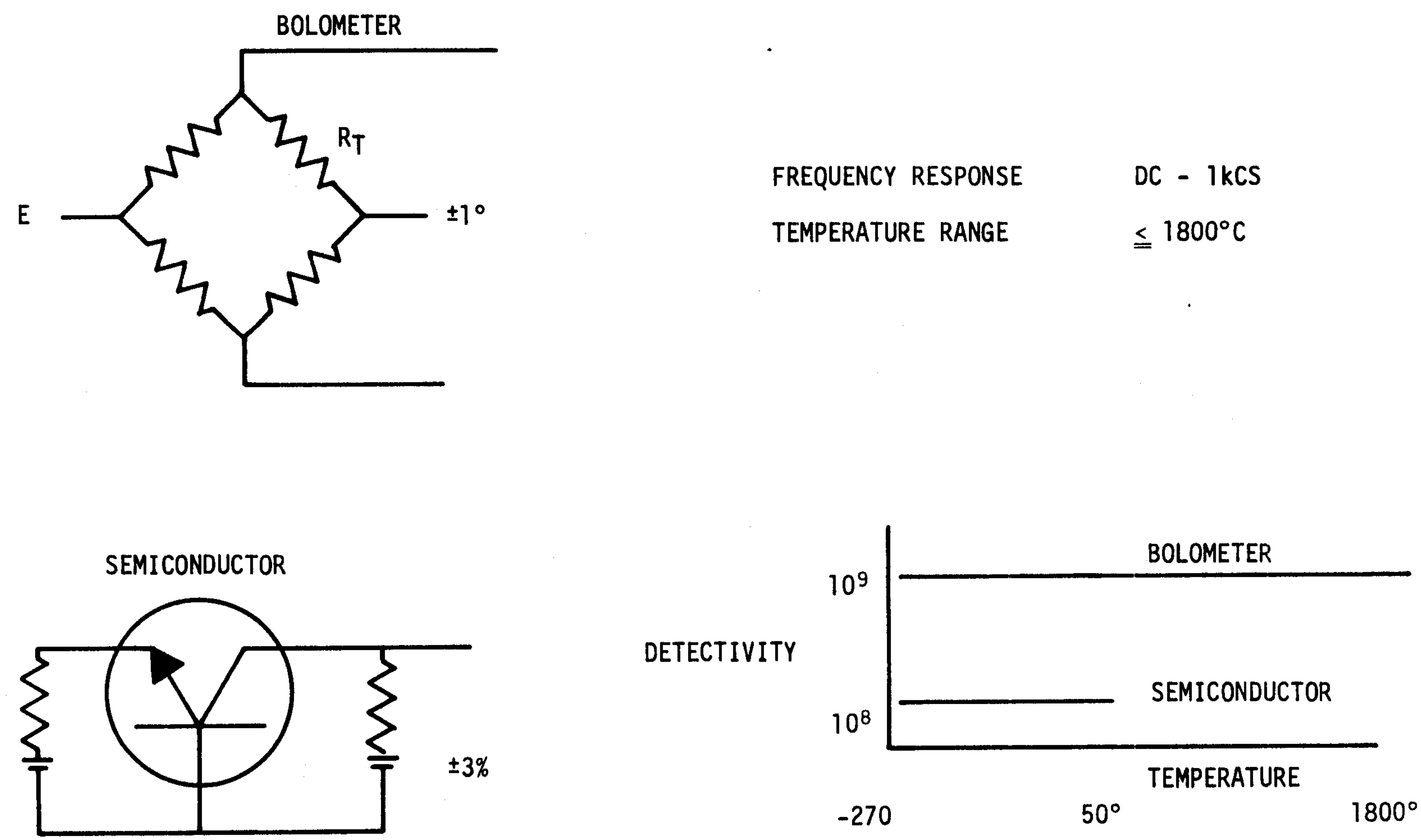


Figure 3-6: THERMAL SENSORS

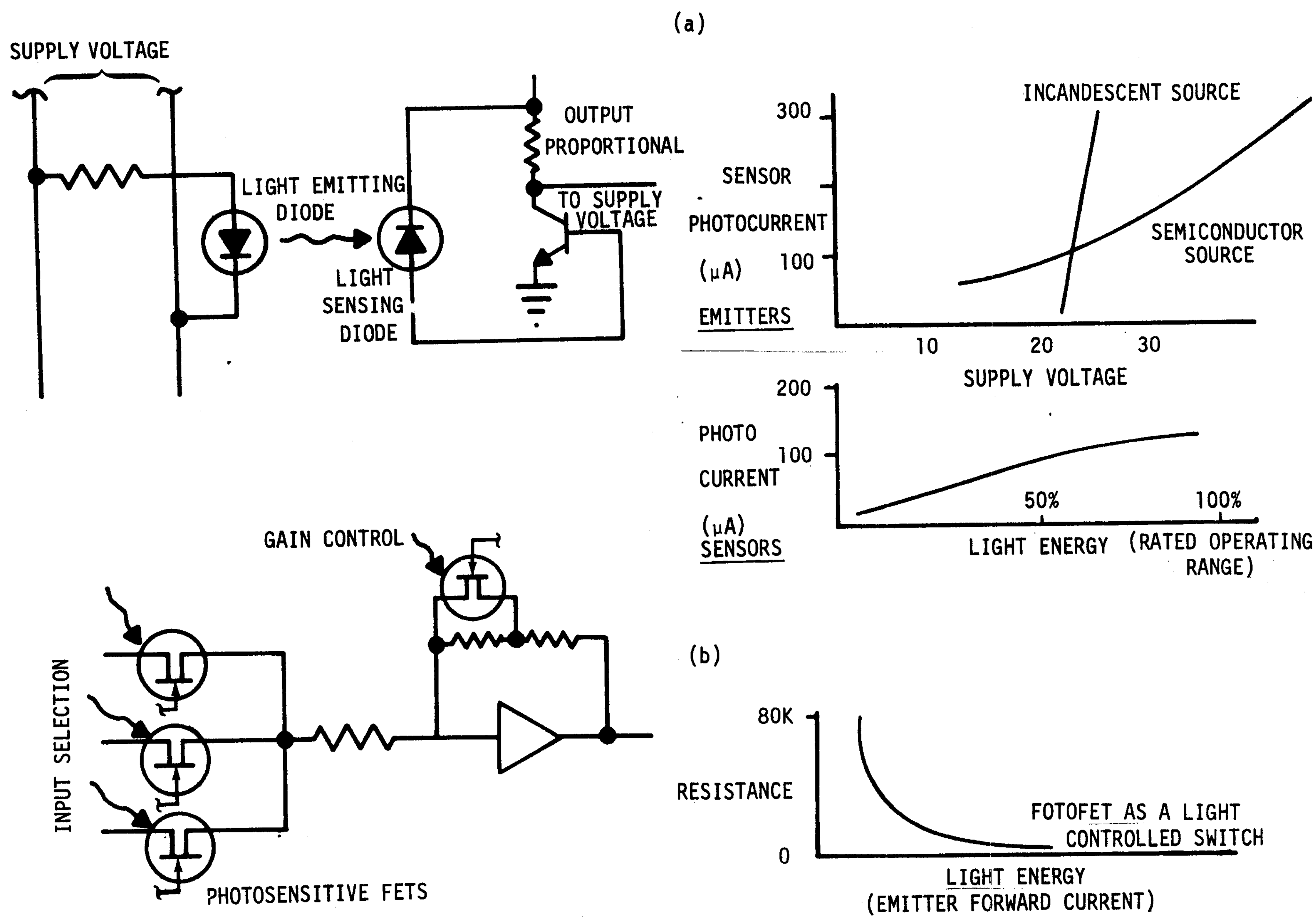


Figure 3-7: OPTOELECTRONICS

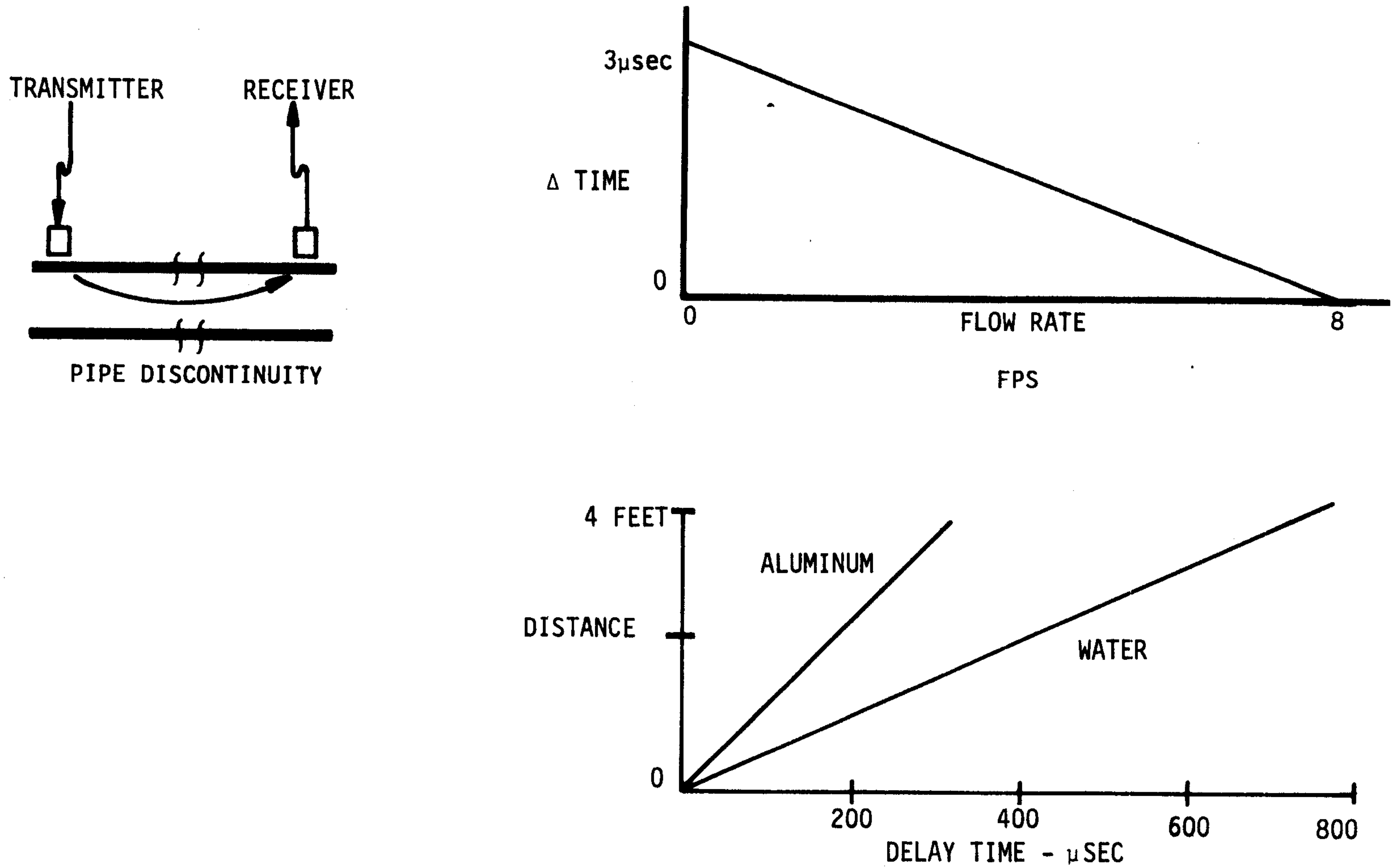


Figure 3-8: ULTRASONIC FLOWMETER

4.0 APPLICATION OF PASSIVE TECHNIQUES TO THE SATURN VEHICLE INSTRUMENT UNIT

To define the types of components to which the selected techniques should be adapted, three iterations of the Instrument Unit were accomplished. First, an assessment of the umbilical connections to the Instrument Unit was accomplished. Volume IV of this final report contains the detailed data sheets that were prepared as a result of this activity. Next, the Instrumentation Program and Component (IP&C) list was analyzed to identify additional parameters requiring instrumentation. Finally, each of the systems and subsystems within the Saturn vehicle Instrument Unit was analyzed to identify current test techniques for these systems.

The types of parameters represented by the numerous umbilical connections to the Instrument Unit have been summarized in Table 4-I. Included also in the table is an assessment as to whether or not the parameter is presently passively instrumented, and where passive instrumentation can be suitable applied. The entry regarding position warrants discussion. Position is presently instrumented utilizing position potentiometers, which are passive in nature. However, due to their poor reliability, the application of the Hall effect device, with magnetic seeding for nonmagnetic actuators, is strongly recommended.

The parameters represented by the IP&C list, present instrumentation assessment, and recommended passive technique are shown in Table 4-II. The comments above concerning position apply here as well.

Table 4-III shows a similar approach for the Instrument Unit subsystems. This third iteration considered each of the subsystem separately, and the parameters required to be monitored or stimulated for an assessment of the system condition were identified.

Table 4-I: INSTRUMENTATION PROGRAM AND COMPONENT APPLICABILITY

PARAMETER	PRESENTLY PASSIVELY INSTRUMENTED	
TEMPERATURE	YES	TRANSISTOR THERMOMETER
FLOW RATE	NO	ULTRASONIC FLOWMETER
PRESSURE	NO	HIGH PRESSURE - STRAIN GAGE
VIBRATION	YES	
POSITION	(YES)	HALL EFFECT, DIFF. GRATING
ACCELERATION	YES	
ACOUSTIC NOISE	YES	
RF POWER	YES	
CURRENT	NO	HALL EFFECT, MAG-RESISTOR
VOLTAGE	NO	MOS-FET ELECTROMETER
FREQUENCY	NO	PHOTO DECOUPLING
DISCRETES	NO	HALL EFFECT (RELAYS)
		PHOTO-COUPLED THRESHOLD
		MOS-FET ELECTROMETER

Table 4-II: UMBILICAL APPLICABILITY

VOLTAGE	NO	MOS-FET ELECTROMETER
CURRENT	NO	HALL EFFECT, MAG-RESISTOR
PRESSURE	NO	STRAIN GAGE - HIGH PRESSURE
TEMPERATURE	YES	TRANSISTOR THERMOMETER
DISCRETES	NO	HALL EFFECT, MAG-RESISTOR
POSITION	(YES)	HALL EFFECT

Table 4-III: SUBSYSTEM APPLICABILITY

SUBSYSTEM	PARAMETER TO BE INSTRUMENTED	RECOMMENDED TECHNIQUES
STATIC INVERTER	OUTPUT TRANSISTORS (BALANCE, REDUNDANCY)	TRANSISTOR THERMOMETER
	ALL FREQUENCIES	PHOTO DECOUPLING
	VOLTAGE	MOS/FET ELECTROMETER
	RF NOISE	NOISE PROBE(S)
	TEMP PROFILES	IR, THERMAL SENSORS
LVDC	CORE DRIVER OUTPUTS	HALL EFFECT
	THERMAL PROFILES	IR, THERMAL SENSORS
	RF NOISE	RF PROBE(S)
	FREQUENCIES	PHOTO DECOUPLING
	CORE DRIVER TEMP. REG. SIMULATION	PELTIER, THERMAL-ELECTRIC
LVDA	RELAY DRIVER CURRENTS	HALL EFFECT
	VOLTAGE	MOS/FET ELECTROMETER
	TEMP PROFILES	IR, THERMAL SENSORS
	RF NOISE	RF PROBE(S)
FLIGHT CONTROL COMPUTER	AMPLIFIER CURRENTS	HALL EFFECT/FLUX CONCENTRATOR
	ACTUATOR DRIVER OUTPUTS	HALL EFFECT, TRANSISTOR THERMOMETER
	AMPLIFIER GAIN STIMULATION	HALL EFFECT, MAG-RESISTOR
	TEMP PROFILES	IR, THERMAL SENSORS
	RF NOISE	RF PROBE(S)
PLATFORM	TORQUER CURRENTS	HALL EFFECT, MAG-RESISTOR
	POSITIONS	ALREADY PASSIVE
	FREQUENCIES	PHOTO DECOUPLING
	RF NOISE	RF PROBE(S)
ENVIRONMENTAL CONTROL	PRESSURE (LOW)	NONE
	FLOW RATE	ULTRASONIC FLOWMETER
	SOLENOID CURRENTS	HALL EFFECT, MAG-RESISTOR
	NITROGEN OUTLET ORIFICE	THERMAL SENSOR
	PRESSURE (HIGH)	NONE
	TEMPERATURES	TRANSISTOR THERMOMETER
POWER	VOLTAGE	MOS/FET ELECTROMETER
	CURRENT	MAGNETORESISTOR
	RELAY STATUS	HALL EFFECT
	RF NOISE	RF PROBE(S)
RF	TRANSMITTER OUTPUT	ALREADY PASSIVE
	RECEIVER TEMP. STAB.	THERMAL SENSOR
	VOLTAGE	MOS/FET ELECTROMETER
	TEMP PROFILES	IR, THERMAL SENSORS
	RF NOISE	RF PROBE(S)

5.0 DEFINITION OF STIMULUS GENERATION AND RESPONSE EVALUATION EQUIPMENT

5.1 INTRODUCTION

The application of new instrumentation techniques to vehicle systems, whether the instrumentation be passive or not, raises a question regarding the equipment with which the instrumentation interfaces. Within the scope of this study, and using the criteria that techniques selected would be applicable for implementation in the reasonably near future, requirements for the evaluation and stimulus generating-programming equipment should include that the equipment be located on-board the vehicle. This requirement is in accordance with the introduction to the contract statement of work, which points out the necessity for space vehicles of the future to function during mission periods lasting many months.

Close coordination has been maintained during the conduct of this study with the Advanced Systems Checkout Design Study, Contract NAS8-20240. A primary purpose of this latter study is the determination of methods and hardware for establishing the concept of airborne evaluation equipment for elements of the Saturn vehicle. The airborne evaluation equipment concept, when implemented, will provide the necessary equipment on-board the Saturn vehicle to accomplish the instrumentation interface functions.

5.2 REQUIREMENTS AND DEFINITIONS

As described in Section 2.0 of this document, the literature search, detailed analysis and study, and the application of certain criteria resulted in the selection of the techniques shown in Table 5-I.

Table 5-I: APPLIED CRITERIA METHODS

HALL EFFECT WITH FLUX CONCENTRATION AND MAGNETIC SEEDING	PHOTON SENSOR
	THERMAL SENSOR
MAGNETORESISTORS WITH MAGNETIC SEEDING	SEMICONDUCTOR EMITTERS AND SENSORS WITH FIBER OPTICS
RF MONITORING	INCANDESCENT EMITTERS WITH FIBER OPTICS
MOS-FET ELECTROMETER	ULTRASONIC FLOWMETER
TRANSISTOR THERMOMETER	

The output level of the sensors shown in Table 5-I is in the range of 10 - 150 millivolts, dependent on the level of the parameter being sensed. Section 3.0 of Volume II of this report shows specifics in this regard. These levels would have to be conditioned if they were to be routed through umbilicals to ground support equipment. However, with the implementation of the airborne evaluation equipment concept discussed in Paragraph 5.1, wherein evaluation equipment is located on the stage proper and therefore close to the instrumentation point, conditioning would not be required.

5.2 (Continued)

The frequency range of the above level measurements is DC to 5 kHz. The ultrasonic flowmeter requires measurement capability at 70 kHz. As with level measurements, these would create problems if routed through umbilicals. Again, however, the approach being taken to on-board evaluation can accommodate these since the on-board equipment contains an AC/DC voltage frequency measuring capability.

As can be seen from the above discussion, the measurements involved can be accomplished by conventional ground support equipment or proposed on-board equipment, but ground measurement would require signal conditioning.

Bias or pump level for Hall effect devices is 100 milliamperes at 200 millivolts. Drive level for photo emitters is 40 milliamperes at 1.3 volts. These devices, essentially, represent the methods recommended for stimulating the Instrument Unit. Therefore, stimulus generation equipment must be capable of driving at these levels. A programmable DC supply or relay switching of DC can accommodate this requirement.

In summary, the requirements imposed on stimulus generation and response equipment are easily met, and impose no limitation on the implementation of passive instrumentation.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The general conclusion reached as a result of this study is that the passive instrumentation concept is feasible, is within the current state of the art, and can be applied (with certain restraints) to the systems of the Saturn vehicle Instrument Unit. When combined with evaluation and generation/programming equipment similar to that described in the Advanced Systems Checkout Design Study, Contract NAS8-20240, the passive instrumentation concept can provide the capability, on-board the vehicle, to passively couple test stimuli into, passively extract responses out of, and evaluate the status of the vehicle systems.

This conclusion is based upon advances in the development of sensors and other devices (electronic, electromechanical, optoelectronic, etc.) which, coupled with utilization of available secondary effects, permit the realization of a system capable of introducing stimuli and extracting responses of vehicle systems without impairing, altering, or affecting the vehicle system operation.

Advances in the field of sensors and devices are being applied to current instrumentation problems on an individual basis. This application occurs as a function of the experience of the design engineer and the ground rules within which he must work.

Available passive techniques have been shown to be powerful tools for achieving isolation between functional systems and the test system.

Maximum effectiveness of the techniques available for passive instrumentation and the coupling of stimulus into systems is obtained only if the functional system is initially designed with knowledge of available techniques and with the intent to utilize them. It is not possible to passively instrument existing systems and obtain the same level of confidence in their operational integrity by this instrumentation that could be obtained from more conventional instrumentation, without modifying the functional system to enhance the application of passive techniques. The foregoing conclusion notwithstanding, many presently inaccessible test points can be monitored by using available passive techniques.

In achieving a passively instrumented system, clear ground rules must be established for the design engineer. He must be encouraged to adopt the desire to, as nearly as possible, provide isolation between the functional system and the test system by utilizing available techniques and devices.

6.2 RECOMMENDATIONS

As a result of information obtained during the course of the study, certain specific recommendations were developed for the next logical step in the implementation of the passive instrumentation concept.

6.2 (Continued)

A test logic study should be accomplished on the functional systems of those elements of the Saturn vehicle required for the conduct of extended missions. Outputs from such a study should include:

a. Identification of test parametres required to determine system status during extended missions;

b. Identification of system parameters which should be continuously monitored during extended missions;

c. Organization of a descriptive test program suitable for on-board implementation and capable of verifying the operational integrity of the functional systems;

d. Modifications required to the functional systems to accommodate the above.

To be conducted concurrently with the test logic development study, certain activities related to the continued development of specific techniques are recommended:

a. Analyze the utilization of all relays and solenoids in the Saturn vehicle and identify those whose operation should be verified during test. Prepare new specifications for all identified items based upon developed prototypes with integral Hall effect or magnetoresistor devices.

b. Accomplish a similar program for all nonmagnetic electromechanical devices (valves, etc.) in the vehicle to prepare specifications for these devices to accommodate a magnetically seeded, Hall effect or magnetoresistor output.

c. Development should be continued on a standard application flux concentrator/Hall-effect measurement device suitable for the passive measurement of current, and applicable throughout the vehicle systems.

d. With recognition of the Saturn vehicle high-power transistor application, development should be initiated on a dual transistor with high power/thermometer capability suitable for direct replacement of existing single-function transistors.

e. Development should be initiated on an additional transistor for use as a thermometer compatible with the Saturn vehicle integrated circuit applications. This transistor thermometer would be an integral part of the integrated circuit.

f. Development should be initiated on a standard transistor thermometer with integral signal conditioning for application in nonelectronic systems.

g. Development should be initiated for a standard, metal-oxide semiconductor field-effect transistor (MOS/FET) electrometer. This electrometer would be intended for use throughout the vehicle systems for the passive measurement of low voltages.

6.2 (Continued)

h. Development should be initiated on a standard flight packaged broad-band RF probe suitable for monitoring the RF radiation attendent to incipient failures in various devices in the vehicle.

i. Additional laboratory work should be accomplished on the application of Hall effect devices in stimulating flight control instruments for the purposes of trouble shooting or fault isolating during test.

Continued developmental work is recommended in the application of optoelectronic techniques for passively extracting signals from, and passively coupling signals into vehicle systems. The feasibility of these techniques has been shown in the laboratory experiments conducted as part of this study. The intent of this recommended effort would be to establish standard devices which would have wide application throughout the vehicle systems.

A design study should be initiated on the electronically scanned IR/optical sensors system discussed in Section 2.2.3m of Volume II of this report.

The development of an ultrasonic flowmeter functional prototype should be accomplished. This flowmeter would be developed in accordance with the techniques described in Section 2.2.5c of Volume II of this report.

It is apparent that for extended missions, systems other than those presently located in the Saturn vehicle Instrument Unit will be required to function either continuously or after extended periods in a quiescent state during the conduct of the mission. The results of the present study have clearly shown the applicability of passive techniques to electronic and electromechanical systems. Many of the systems required for extended missions, however, will be nonelectronic. Therefore, it is recommended that additional development work be accomplished to define passive techniques for nonelectronic extended mission systems other than located in the Instrument Unit.

The above recommendations represent a continuation of work on the passive instrumentation concept on a broad front, and will make available many of the elements necessary for the implementation of the concept. Parallel with this activity, the onboard evaluation and generation/programming system development must proceed. The equipment described in the Advanced Systems Checkout Design Study, Contract NAS8-20240, could serve as the basis for such a system.

The feasibility of passive instrumentation on space vehicle systems has been clearly established in this study, and the implementation of this concept appears to be straightforward.